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PEOPLES REPUBLIC OF CHINA NATIONAL STANDARD
LASER RADIATION OCCUPATIONAL HEALTH STANDARD

FOREIGN TECHNOLOGY DIVISION

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HUMAN TRANSLATION

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PEOPLES REPUBLIC OF CHINA NATIONAL STANDARD

LASER RADIATION OCCUPATIONAL HEALTH STANDARD

As far as the long term exposure to laser radiation of a certain strength by laser workers is concerned, it is possible for it to give rise to reductions in visual acuity, clouding of lenses, as well as headaches, anemia, nerve weakness, and other similar bad effects throughout the entire body. The potentially problem causing laser radiations are capable of leading to severe acute disorders. Because of this, personnel in contact with lasers (exclusive of those receiving laser diagnosis and treatment) should receive strengths of radiation which are definitely limited.

The wavelengths of laser radiation are from 200nm-1mm. The maximum permissible amounts of radiation (or degree of radiation) are not only related to wavelength, but also, have a close relationship with the duration of the radiation received. The maximum permissible amounts of radiation for the human body (MPE) take the two organs of the eyes and the skin as the standards, and the actual standards can be seen at I and II.

See appendix A for the regulations specifying the extreme limit apertures for the measurements of eyes and skin MPE.

Chinese language, translation. (orig.)

1 波长 (nm)	2 照射时间 (s)	3 最大容许照射量
4 紫外		
200–302	10^{-9}–3×10^{4}	3×10^{-3} J·cm^{-2}
303	10^{-9}–3×10^{4}	4×10^{-3} J·cm^{-2}
304	10^{-9}–3×10^{4}	6×10^{-3} J·cm^{-2}
305	10^{-9}–3×10^{4}	1.0×10^{-2} J·cm^{-2}
[illegible]	10^{-9}–3×10^{4}	1.6×10^{-2} J·cm^{-2}
307	10^{-9}–3×10^{4}	2.5×10^{-2} J·cm^{-2}
308	10^{-9}–3×10^{4}	4.0×10^{-2} J·cm^{-2}
309	10^{-9}–3×10^{4}	6.3×10^{-2} J·cm^{-2}
310	10^{-9}–3×10^{4}	1.0×10^{-1} J·cm^{-2}
311	10^{-9}–3×10^{4}	1.6×10^{-1} J·cm^{-2}
312	10^{-9}–3×10^{4}	2.5×10^{-1} J·cm^{-2}
313	10^{-9}–3×10^{4}	4.0×10^{-1} J·cm^{-2}
314	10^{-9}–3×10^{4}	6.3×10^{-1} J·cm^{-2}
315–400	10^{-9}–10	$0.56t^{1/4}$ J·cm^{-2}
315–400	10–10^{3}	1 J·cm^{-2}
315–400	10^{3}–3×10^{4}	1×10^{-3} W·cm^{-2}
5 可见		
400–700	10^{-9}–10^{-5}	5×10^{-7} J·cm^{-2}
400–700	10^{-5}–10	$2.5t^{3/4}\times10^{-3}$ J·cm^{-2}
400–700	10–10^{4}	$4C_B\times10^{-3}$ J·cm^{-2}
400–700	10^{4}–3×10^{4}	$C_B\times10^{-6}$ W·cm^{-2}
6 红外		
700–1050	10^{-9}–10^{-5}	$5C_A\times10^{-7}$ J·cm^{-2}
700–1050	10^{-5}–10^{3}	$1.8C_At^{3/4}\times10^{-3}$ J·cm^{-2}
1050–1400	10^{-9}–10^{-5}	5×10^{-6} J·cm^{-2}
1050–1400	10^{-5}–10^{3}	$12.5t^{3/4}\times10^{-3}$ J·cm^{-2}
700–1400	10^{3}–3×10^{4}	$320C_A\times10^{-6}$ W·cm^{-2}
7 远红外		
1400–10^{6}	10^{-9}–10^{-7}	10^{-2} J·cm^{-2}
1400–10^{6}	10^{-7}–10	$0.56t^{1/4}$ J·cm^{-2}
1400–10^{6}	>10	0.1 W·cm^{-2}

8 注：波长（λ）为：

400–700nm	$C_A = 1$
700–1050nm	$C_A = 10^{0.002(\lambda-700)}$
1050–1400nm	$C_A = 5$
400–550nm	$C_B = 1$
550–700nm	$C_B = 10^{0.015(\lambda-550)}$

1. Wavelength 2. Radiation Time 3. Maximum Permissible Amount of Radiation 4. Ultraviolet 5. Visible 6. Infrared 7. Far Infrared 8. Note: Wavelength (λ) is:

① 表Ⅱ 激光照射皮肤的最大容许照射量

②光谱范围	③波 长(nm)	④照射时间(s)	⑤最大容许照射量
紫 ⑥ 外	200—400	10^{-9}—3×10^{4}	同 ⑦表 I
可 ⑧ 见 与 红 外	400—1400	10^{-9}—10^{-7}	$2C_A\times10^{-2}$ J/cm²
	400—1400	10^{-7}—10 $10-3\times10^{4}$	$1.1C_At^{1/4}$ · J/cm² $0.2\,C_A$ W/cm²
⑨远红外	1400—10^{6}	10^{-9}—3×10^{4}	同 ⑩表 I

⑪表中 C_A 同表 I 注

1. Table II Maximum Permissible Amounts of Radiation to the Skin 2. Spectrum Range 3. Wavelength 4. Radiation Time 5. Maximum Permissible Amount of Radiation 6. Ultraviolet 7. Same as Table I 8. Visible and Infrared 9. Far Infrared 10. Same as Table I 11. In table, C_A same as Table I Note

Appendix A Test Standards for Laser Radiation

A.1 Scope of Appropriate Use

These standards are appropriate for use in the measurement of maximum permissible amounts of radiation for operator personnel coming in contact with laser devices and laser device systems.

A.2 Standard Content

A.2.1 Laser devices require adjustment to maximum output levels. Measurements are carried out under conditions eliminating randomly scattered wavelengths of light not to be measured.

A.2.2 As far as the measurement of maximum permissible amounts of radiation which can be directed from laser devices and laser device systems onto eyes and skin is concerned, this should be carried out in the work area of laser operator personnel. The receptors of laser radiation measuring devices should be positioned in the light bundle or sheaf, in order to get the maximum radiation strength level in the center of the radiation sheaf as the standard or basis.

A.2.3 The maximum circular area and diameter for measuring the maximum permissible amounts of radiation is the limit or extreme limit aperture. When measuring maximum permissible amounts of radiation for the eyes, the wavelengths are 200-400nm and 1400-10^6 nm using a 1 mm aperture. With wavelengths of 400-1400nm, 7 mm apertures are used. When measuring the maximum permissible amounts of radiation for the skin, 1 mm apertures are always used.

A.3 Measuring Instruments

On the basis of laser device output wavelengths and output levels, one selects appropriate measuring devices.

A.3.1 When one is using a 1 mm limit aperture measurement output level, the measuring device receptor heads' sensitivity must be 5
uniform.

A.3.2 Measuring devices should all be calibrated through the National Measures Ministry. The measurement error (including the original laser output) must not exceed 2(numbers unclear) %.

A.3.3 During measurements, medium and small power laser devices make use of conical cavity thermoelectric type power meters. Small energy laser devices make use of photoelectric type energy meters. For large power laser devices, one selects for use the continuous measurement thermal type power meter.

Explanation of Formulation

In September of 1961, our country created the first red ruby laser device. Over more than the last twenty years, laser technology has rapidly developed. Moreover, in such fields as industry, agriculture, medicine, the military, and science and technology, as well as other similar realms, it has acheived a daily broadening of its applications.

At the present time, all through our country, there are something over three hundred research and production units handling lasers and their applications. Among these, there are somewhere over 200 factories and approximately 100 research units. Personnel involved in handling laser work are approaching more than ten thousand (and this does not include the medical personnel handling laser therapy).

Commercial products for the domestic industrial application of lasers number something over thirty types. Among these, the important laser devices are: helium-neon, mixed neodymium-yttrium-aluminum garnet, carbon dioxide, argon ion, red ruby, tunable or harmonic dye, gallium arsenide semiconductor and other similar laser devices. In medicine, military uses, and such areas as scientific research, the laser devices used are also prinicipally of the types described above. Among these types of laser devices, taking the lowest power He-Ne laser device as an example, its output is generally always larger than 1mw. Its radiation level already exceeds the currently existing class 2 laser device levels in the international laser protection standards. On this basis, personnel in contact with laser devices are all capable of receiving damage from laser radiation. In line with the continuous nature of the new type of laser devices, the range of their applications has gradually expanded, and one can predict that personnel in contact with lasers are going to become more and more numerous. In order to carry out in concrete terms the guidance that "prevention is the main thing" and that one should "protect the environment and bring happiness to the people", it is absolutely necessary to set up as quickly as possible protective standards for lasers which fit the situation of our country and the peculiarities of oriental people.

The central problem of research into protective laser safety standards is to understand the biological effects of lasers. Our country, in 1965, began work in this area. Concerned units then carried out large amounts of experimental research on the effects of lasers on eyes, skin, blood, and nervous systems, obtaining definite biological data. At the end of the 1970's, there were a number of 7
scholars who carried out investigations into the microstructural changes in the visera of animals after irradiation from Nd:YAG lasers, into the effects on rabbit eyes of nitrogen molecule lasers, and quantitative measurements of thermal transmission in biological tissues from carbon dioxide lasers and neodymium-yttrium-aluminum garnet lasers. After that, there were also several reports on the effects of argon ion lasers on micronucleoli, developing the discussion of such questions as whether or not lasers give rise to chromosome transmitted deformities. However, the necessity to set up standards required that there be large amounts of acute experimental material on laser damage thresholds. Internationally, beginning from the 1960's, research in this area was begun. Primary in this was to measure, for the various types of wavelengths of laser light, the threshold values for damage to the eyes and skin. Normally, the amount of laser light radiation for which it was observed that there was at least a 50% probability of damage was taken as the damage threshold. The damage thresholds for eyes and skin were respectively represented by ED_{50} and MRD_{50}. Due to the fact that ED_{50} and MRD_{50} are arrived at through the analysis of large amounts of statistical data, there is the possibility that, from the distribution of these values, one can evaluate the maximum permissible amounts of radiation for eyes and skin from the various wave bands of lasers. The scholars of various nations, in regard to this matter, have already carried out large amounts of research (for details, see annex 1).

China, as far as the matter of laser effects is concerned, has been of relatively great world significance, and, in order to act as a great power, she ought to give serious attention to the safety of the use she makes of laser devices. Moreover, she should set out appropriate safety standards for lasers. On the basis of widespread reaction from laser workers, in September 1981, concerned technicians from organizations of the national science and technology commision began discussions on research problems associated with laser

protection standards. With members of the commision, they reviewed the practical applicaitons of lasers over the last more than twenty years, acknowledging specifically the harm done to human bodies, particularly to eyes and skin. Several score of reports on acute eye damage accidents, which were collected from various places, showed that laser light from a non-directional ordinary light source, whose strength is high, and, with a small angle of divergence, even with reflected or diffused laser light, is capable of harming the eyes. It is generally recognized that, on the foundation of our country's early biological research on lasers, we should, as quickly as possible, delve deeply into research on the development of laser protective standards. After confering, organizations of the national science commission such as the No.2 Shanghai Medical Academy, the Chinese Academy of Military Medicine and Science, the No.1 Shanghai Medical Academy, the Guangzhou Zhongshan Medical Academy, the Xian Medical Academy, the China Measures and Scientific Research Academy, the Tianjin City Labor Health Research Institute, the Tianjin City Laser Research Institute, the Tianjin City Academy of Opthalmic Medicine, and other similar units formed the All China Laser Protective Standards Research Cooperation Team. At the same time they issued research topics on the measurement of threshold values for the eyes and skin, requiring, on the basis of experimental research, to make suggestions for laser safety protective standards.

The cooperative research team, on the basis of materials from 8
research on laser safety standards outside China and on the actual status of the utilization of laser devices inside of China, set up a practical plan for experimentation. From the end of 1981 to the beginning of 1985, the cooperative research team carried out large amounts of biological testing. They did measurements on eight commonly used types of laser devices (11 wavebands) and their damage thresholds on the eyes and skin. In order to guarantee the precision and reliability of the totality of the research results, rigorous standards were established in such areas as the requirements for laser devices and laser systems, amounts of radiation doses, data handling, indicators for biological observations, and other similar items.

In the whole of the experiments done to measure the damage thresholds for laser light on the eyes and skin, the stability of the outputs from the laser light sources selected for use was in all cases ± 5%. Continuous outputs all made use of single-type devices. The national academy of measures carried out periodic calibrations on the measuring devices used in this research. The biological tests, besides the observations made with the naked eye, were also checked for their histology by large amounts of observation with optical and electron microscopes. The statistical analysis methods in the experimental data used as references the international reports on experiments of the same type. The specifications and standards discussed above guaranteed that, in the draft of these standards, the maximum permissible amounts of radiation concerned were set on a reliable basis. Below are the results of the experimental research and a simple comparison between them and the corresponding international biological material as well as a comparison of the two.

As far as research into the damage thresholds for laser light on eyes is concerned, it was decided to select for use animal types with low eye pigmentation and with a relatively close affinity to man, such as, greenish blue, purple (deep blue), blue, and grey rabbits, as well as monkeys. Eight types of laser light wavelengths were used. Irradiations were carried out over different exposure times. And, data for 31 ED_{50}'s was obtained (see Table 1 and annex 2).

As far as research on damage to the skin from laser light is concerned, it was decided to select for use small white pigs as the animal type, since they are appropriate for transfer of data to experiments on the human body. Eight types of laser light wavelengths were also used. Irradiations were carried out over different time intervals. Researchers acquired data for 20 MRD_{50} amounts of radiation with a probability of 50% for the appearance of visible red striations on the skin (see Table 2 and annex 3)

Currently , international evaluations for the damage thresholds of laser light were all selected for use by probabilistic and statistical analytical methods. On the basis of the requirements of health statistics, the rates of slope in probability analysis require a high degree of accuracy, that is, the low probability point (10% or 20% probability of damage) or the high probability points (90% or 80% probability of damage) and their ratio or comparison to the 50%

① 表1 激光对眼的损伤阈 (ED_{50})

②波长 (nm)	③实验对象	④照射时间 (s)	⑤视膜上光斑直径 (mm)	⑥视膜上入射的能量密度或功率密度 (J/cm² 或 W/cm²)	⑪备注
222	⑦兔眼	8×10^{-9}	1	54.4×10^{-3} J/cm²	[illegible]
308	⑦兔眼	$8\text{–}10 \times 10^{-9}$	1	0.83 J/cm²	[illegible]
488	⑦兔眼	1×10^{-1}	2.76	0.51 W/cm²	[illegible]
488	⑦兔眼	1.45×10^{-1}	3	0.50 W/cm²	[illegible]
488	⑦兔眼	1	2.76	0.43 W/cm²	[illegible]
488	⑦兔眼	1	3	0.40 W/cm²	[illegible]
488	⑧猴眼	1×10^{-1}	2.76	0.834 W/cm²	[illegible]
488	⑧猴眼	1.45×10^{-1}	3	1.8 W/cm²	[illegible]
488	⑨黄种人眼	1×10^{-1}	2.76	1.76 W/cm²	
488	⑨黄种人眼	1.45×10^{-1}	0.833	17.65 W/cm²	
530	⑦兔眼	5×10^{-9}	5	39.2×10^{-6} J/cm²	
530	⑦兔眼	8×10^{-9}	4	232.1×10^{-6} J/cm²	
530	⑧猴眼	5×10^{-9}	5	187×10^{-6} J/cm²	
632.8	⑦兔眼	1	4.3	178×10^{-3} W/cm²	
632.8	⑦兔眼	1.25×10^{-1}	4.3	215×10^{-3} W/cm²	
694.3	⑦兔眼	6×10^{-4}	5	14.9×10^{-3} J/cm²	
694.3	⑦兔眼	7×10^{-4}	5	16.6×10^{-3} J/cm²	
694.3	⑧猴眼	7 × 10[illegible]	5	42.5×10^{-3} J/cm²	
1060	⑦兔眼	5×10^{-9}	5	1.2×10^{-3} J/cm²	
1060	⑦兔眼	1.5×10^{-4}	1.5	97.6 W/cm²	
1060	⑦兔眼	1.2×10^{-1}	5	5.4 W/cm²	
1060	⑦兔眼	1.37×10^{-1}	1.7	67.2 W/cm²	
1060	⑦兔眼	1	1.7	17.5 W/cm²	
1060	⑦兔眼	1.02	5	2.5 W/cm²	
1060	⑧猴眼	1.5×10^{-4}	1.5	333.3 W/cm²	
1060	⑧猴眼	5×10^{-9}	5	4.3×10^{-3} J/cm²	
1060	⑨黄种人眼	1.5×10^{-4}	1.75	429 W/cm²	[illegible]
10600	⑦兔眼	1.2×10^{-1}	1	10.7 W/cm²	[illegible]
10600	⑦兔眼	1.25×10^{-1}	1	4.0 W/cm²	[illegible]
10600	⑦兔眼	1	1	3.6 W/cm²	[illegible]
10600	⑦兔眼	1.03	1	5.7 W/cm²	[illegible]

⑩ [illegible]

1. Table 1 (number unclear) Damage Threshold of Laser Light on Eyes (ED_{50}) 2. Wavelength 3. Object of Experimentation 4. Irradiation Time 5. Diameter of Light Striations on the Retina (unclear) 6. Radiation Power Density on Retina (unclear) and Power Denstiy 7. Rabbit Eye 8. Monkey Eye 9. Oriental Person's Eye 10. Duration of Damage Sustained on Retina (unclear) 11. Remarks

① 表2 激光对皮肤的损伤阈 (MRD_{50})

激光波长 ② nm	实验对象 ③	照射时间 ④ s	光斑直径 mm ⑤	MRD_{50} J/cm²
10600	⑥白猪	1	5	3.7
10600	⑥白猪	1	5	2.4
10600	⑦黄种人	1	5	2.7
10600	⑦黄种人	1	5	2.3
1060	⑥白猪	1	5	59.4
1060	⑥白猪	2×10^{-4}	5	4.6
1060	⑦黄种人	1	5	60.6
1060	⑦黄种人	1	5	71.4
1060	⑦黄种人	2×10^{-4}	5	9.9
1060	⑦黄种人	3×10^{-4}	5	20.3
694.3	⑥白猪	3.2×10^{-4}	5	53.3
694.3	⑦黄种人	3.2×10^{-4}	5	4.7
514.5	⑦黄种人	1	5	7.1
488	⑧杂交灰猪	1	5	5.2
488	⑨黄种人	1	5	5.6
488	⑨黄种人	1	5	5.6
337.1	⑥白猪	4.5×10^{-9}	5	8.3
306	⑥白猪	15×10^{-9}	5	53.8×10^{-3}
308	⑥白猪	$50\text{-}70 \times 10^{-9}$	5	73.0×10^{-3}
265	⑥白猪	9×10^{-9}	5	22.0×10^{-3}

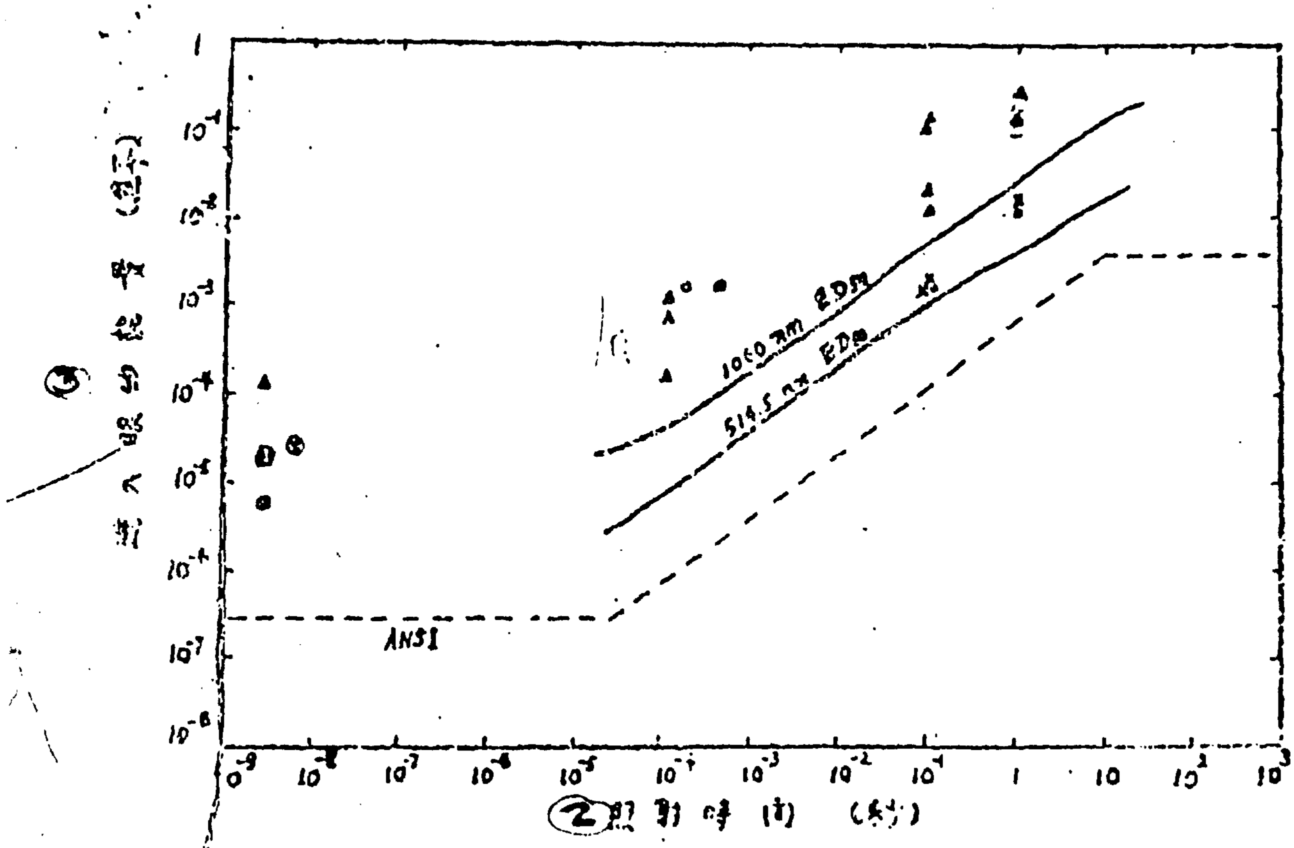
5

1. Table 2 Damage Thresholds for Laser Light on Skin 2. Laser Light Wavelength 3. Test Object 4. Radiation Time 5. Light Striations of Faculae Diameter 6. White Pig 7. Oriental Person 8. Hybrid Grey Pig (unclear)

probability of damage are very important data. In the research in question, ED_{50}/ED_{10}=1.2--2.2. MRD_{50}/MRD_{10}=1.2-3.1. The specific values are all larger than 1. Because of this, it is possible from ED_{50} or MRD_{50} to evaluate safe radiation levels. The currently existing international laser protective standards' maximum permissible exposure--MPE-- or exposure limit--EL--compared to the ED_{50} or MRD_{50} values are 5-20 times lower. This multiplier value is due to a safety factor. Its size is not only decided upon on the basis of the overall errors in acute tests and the amplitudes of calculated MPE value individual deviations. It is also necessary to consider the long term chronic effects of laser radiation, the degree of reversibility of damage received by organisms, and other similar factors. In comparisons with research of the same type outside of China, the larger part of our ED_{50} data are on the high side to some extent (as shown in Table 1). The MRD_{50} data is basically located in the interval between the MRD_{50} for white men and black men (see Table 5). The errors in research results and experimental methods, the indexes or targets of the biological reactions observed, the environmental factors, the individual errors, and other similar factors are all related to this. However, from comparisons, it is possible to see that many wavebands have ED_{50} and MRD_{50} which are still quite close. Because of this, it is possible to refer to the advanced international laser protective standards in setting up our country's standards.

In this research, five types of laser light wavelengths produced numbers from experiments on damage threshold values for skin, with 120 volenteers participating, which show that the data for oriental people are greatly in excess of those for reports of a similar nature outside China. Besides this, the 265 nm (Nd:YAG four fold frequency laser device) and the 222 nm and 308 nm quasi-molecular ultraviolet laser devices, in research on the damage thresholds for skin and eyes, at the present time, still have no similar types of reports coming from outside China. These furnish biological data for setting up ultraviolet laser light protection standards.

The cooperative team, besides completing the basic biological experiments described above, also carried out investigative research in Beijing, Shanghai, Xian, Tianjin, Hebei, Dongbei, Guangzhou, and other similar places. From the large quantities of first hand checks by the actual workers as well as their subjective reactions, one comes to understand that, as far as laser light is concerned, it is necessary to adopt for use some set of protective measures. At the same time as this, we also organized our strength and translated the most important international laser safety protective standards (see annexes 4-6). Moreover, we collected several hundred works by relevant experts. On the basis of research and analysis of international standards, the cooperative team brought forward suggested laser light protective standards. These were sent through 12 relatively famous units handling research on lasers, and they put forward their suggestions for corrections. Finally, on the basis of experimental research, this staffing draft was written.



1 图1 本实验眼睛ED_{50}与国外资料的比较

---- ANSI 的眼MPE — 国外资料汇集线（514.5 nm 与1060 nm 的ED_{50}）

■ 458 nm，• 632.8 nm，○ 694.3 nm，⊕ 530 nm

④本实验ED_{50}：▲ 1064 nm，

1. Fig. 1 A Comparison of the Eye ED_{50} in These Experiments and Materials from Outside China 2. Irradiation Time (Sec) 3. Approximate Total Energy Entering the Eye (Joules) 4. (Many characters unreadable) These Experiments' ED_{50}

①表3 中国人皮肤MRD_{50}与国外资料的比较 (Ratio of MRD_{50} to MPE)

②激光器	③波长 nm	④照射时间 s	⑤试验对象	MRD_{50} J/cm^2	MPE J/cm^2	~~MRD_{50}/MPE~~ (MRD_{50}与MPE之比)⑥
Ruby	694.3	2.5×10^{-3}	9白人	11–20	0.25	44
		2.5×10^{-3}	8黑人	2.2–6.9	0.25	9
		0.32×10^{-3}	9中国人	4.2–5.1	0.147	28
Nd-Glass	1060	75×10^{-9}	9白人	4.2–5.7	0.1	42
		75×10^{-9}	8黑人	2.5–3.0		25
		2×10^{-4}	9中国人	9.3–10.6	0.65	14
		3×10^{-4}	9中国人	19.0–21.9	0.72	26
CO_2	10600	1.0	7白人	2.8	0.56	5
		1.0	8黑人	2.8		5
		1.0	9中国人	2.3–2.7	0.56	4
Nd:YAG	1060	1.0	7白人	48–78	5.5	9
	1060		8黑人	46–60		8
			9中国人	60–71		11
Ar^+	488	1.0	7白人	4.0–8.2	1.1	4
			8黑人	4.5–6.0		4
			9中国人	5.6–5.64		5

1. Table 3 A Comparison of the MRD_{50} of Chinese to Materials from Outside of China 2. Laser Device 3. Wavelength 4. Irradiation Time 5. Object of Experiment 6. Ratio of MRD_{50} to MPE 7. White People 8. Black People 9. Chinese

Below, we make a simple explanation of the maximum permissible doses of radiation (Table I and Table II) as set out in these standards. The key to the evaluation of MPE is our reference to the size of the safety factor in our considerations. Due to the fact that the light spectrum of the laser light is relatively broad--from ultraviolet all the way across to the far infrared--the various amounts absorbed by the eye from light of different wavelengths is different. This is also the case with the skin. Because of this, it is necessary to select for use optical spectrum factors C_A and C_B and carry out adjustments of MPE for various wavelengths. The various wavelengths of light can be divided into three types on the basis of their mechanisms of effect on biological tissues. First, in the case of non-linear effects, for example, one has multiple photon absorption, Raman and Brillouin effects, instantaneous ultrasonics, single state oxygen absorption, and other similar phenomena, which often occur in this process during radiation periods in the range of 10^{-9}-10^{-6} seconds. When the irradiation time lies between 10^{-5}-10 seconds, the laser light's effects on the eyes and skin are primarily thermal effects. When the irradiation period is in the 10-10^{3} second range, certain wavebands must be considered in terms of the two types of mechanisms of photochemical effects and thermal effects. When the durations are larger than 10^{3} seconds and up to 8 hours (appoximating 3×10^{4} seconds), then, it is necessry to consider the chronic damaging effects of long term irradiation. Because of this, when establishing maximum permissible doses of radiation for laser light, the light wavelength and the irradiation time are the two most important factors. The order of the irradiation time and the damaging mechanisms of the light on biological tissues are definitely related to each other.

1 表I 眼直视激光束的最大容许照射量

2 波长（nm）	3 照射时间（S）	4 最大容许照射量
5 紫外		
200—302	10^{-2}—3×10^{4}	3×10^{-3} J·cm^{-2}
303	10^{-2}—3×10^{4}	4×10^{-3} J·cm^{-2}
304	10^{-2}—3×10^{4}	6×10^{-3} J·cm^{-2}
305	10^{-2}—3×10^{4}	1.0×10^{-2} J·cm^{-2}
306	10^{-2}—3×10^{4}	1.6×10^{-2} J·cm^{-2}
307	10^{-2}—3×10^{4}	2.5×10^{-2} J·cm^{-2}
308	10^{-2}—3×10^{4}	4.0×10^{-2} J·cm^{-2}
309	10^{-2}—3×10^{4}	6.3×10^{-2} J·cm^{-2}
310	10^{-2}—3×10^{4}	1.0×10^{-1} J·cm^{-2}
311	10^{-2}—3×10^{4}	1.6×10^{-1} J·cm^{-2}
312	10^{-2}—3×10^{4}	2.5×10^{-1} J·cm^{-2}
313	10^{-2}—3×10^{4}	4.0×10^{-1} J·cm^{-2}
314	10^{-2}—3×10^{4}	6.3×10^{-1} J·cm^{-2}
315—400	10^{-9}—10	$0.56t^{1/4}$ J·cm^{-2}
315—400	10—10^{3}	1 J·cm^{-2}
315—400	10^{3}—3×10^{4}	1×10^{-3} W·cm^{-2}
可见光		
400—700	10^{-9}—10^{-5}	5×10^{-7} J·cm^{-2}
400—700	10^{-5}—10	$2.5t^{3/4}\times10^{-3}$ J·cm^{-2}
400—700	10—10^{4}	14×10^{-3} J·cm^{-2}
400—700	10^{4}—3×10^{4}	$C_B\times10^{-5}$ W·cm^{-2}
6 红外		
700—1050	10^{-9}—10^{-5}	$5C_A\times10^{-7}$ J·cm^{-2}
700—1050	10^{-5}—10^{3}	$1.8C_At^{3/4}\times10^{-3}$ J·cm^{-2}
1050—1400	10^{-9}—10^{-5}	5×10^{-6} J·cm^{-2}
1051—1400	10^{-5}—10^{3}	$12.5t^{3/4}\times10^{-3}$ J·cm^{-2}
700—1400	10^{3}—3×10^{4}	$320C_A\times10^{-6}$ W·cm^{-2}
7 远红外		
1400—10^{6}	10^{-9}—10^{-7}	10^{-2} J·cm^{-2}
1400—10^{6}	10^{-7}—10	$0.56t^{1/4}$ J·cm^{-2}
1400—10^{6}	>10	0.1 W·cm^{-2}

8 注：波长（ ）为：

400—700nm	$C_A=1$
700—1050nm	$C_A=10^{0.002(\lambda-700)}$
1050—1400nm	$C_A=5$
400—550nm	$C_B=1$
550—700nm	$C_B=10^{0.015(\lambda-550)}$

1. Table I Maximum Permissible Doses of Radiation for Direct Observation of the Light Bundle by the Eye 2. Wavelength 3. Radiation Time 4. Maximum Permissible Dose of Radiation 5. Ultraviolet 6. Infrared 7. Far Infrared 8. Note: Wavelength (λ) is:

① 表Ⅱ 激光照射皮肤的最大容许照射量

②光谱范围	③波长（nm）	④照射时间（S）	⑤最大容许照射量
⑥紫外	0.200—0.400	10^{-9}—3×10^{4}	⑩同表Ⅰ
⑦可见	0.400—1.400	10^{-9}—10^{-7}	$2C_A\times10^{-2}$ J/cm²
⑧红外	0.400—1.400	10^{-7}—10	$1.1C_A t^{1/4}$ J/cm²
⑨远红外	1.400—1000	10^{-9}—3×10^{4}	⑩同表Ⅰ

1. Table II Maximum Permissible Doses of Laser Light Radiation on the Skin 2. Light Spectrum Range 3. Wavelength (nm) 4. Radiation Time 5. Maximum Permissible Dose of Radiation 6. Ultraviolet 7. Visible 8. Infrared 9. Far Infrared 10 Same as Table I

The ultraviolet wave band MPE set up. resulted from consulting the international WHO 1979 non-laser ultraviolet light standards promulgated in 1979. At the same time, we also checked for verification the MPE values for several wave bands on the eyes and skin. These standards, in the U and V wave bands, had safety factors which were in the neighborhood of 5~20. (Example)

Visible light wave bands. A comparison between the research data in question and the data from outside of China (Table 4) can be seen in Fig.1 and Fig.2. The data from these experiments is a bit on the high side. The basis was 4 wave bands (488, 530, 632.8, and 694.3 nm), 4 radiation times (10^{-9}, 10^{-4}, 10^{-1} and 1 second) and their ED_{50} distributions. We determined the MPE evaluation of safety factors for (1) the 10^{-9}-10^{-5} Table to be 80~100. Moreover, the MP MPE values in 400~700nm were 5×10^{-7}J/sq.cm. (2) As far as the second band radiation time 10^{-5}-10 seconds is concerned, one can see, in Fig.1 and Fig.2, that ED_{50} is primarily related to the radiation time t. There is no clear relationship with the light spectrum factor. This time, the safety factors were selected in the range 50~150. The MPE value used was $2.5t^{3/4}\times10^{-3}$J/sq.cm. This value calculates to be 1.4 times the international standard. (3)

① 表4 具代表性的各国学者关于眼受激光照射的 ED_{50} 数据

② 波长	③ 照射部位	④ 照射时间	⑤ 视网膜象直径	⑥ 进入角膜的能量	⑦ 到达视网膜的能量	⑧ 作者
λ (nm)		t (s)	d_r (μm)	Q_c (mJ)	H_r (J/cm²)	
514.5	EM	0.004	15	0.14	79	Vassiliadis, 1971
514.5	EM	1.0	50	5.5 (3.0)	280	Beatrice & Frisch, 1973
514.5	EM	1.0	540	32(20)	14	
514.5	EM	1.0	940	50(40)	7.3	
514.5	EM & M	1.0	500	16.3	15.3	Ham *et al.*, 1976
514.5	EM & M	16	500	185	165	
514.5	EM & M	100	500	250	220	
514.5	EM & M	1000	500	360	320	
514.5	M	1000	70 ?	120	3100	Gibbons & Allen, 1976
514.5	EM & M	14400	15000	500000	200	Lawwill *et al.*, 1977
532	M	15×10^{-9}	40	0.003	0.24	Gibbons, 1973
[illegible]	M	0.016	40	0.40	32	Dunsky & Lappin, 1971
[illegible]	EM & M	0.25	50—80	3.3 (1.5)	170	Ham *et al.*, 1970
632.8	M	0.5	40	6.0 (5.5)	400	Lappin & Coogan, 1970
632.8	EM & M	1.0	500	63(55)	30	Ham *et al.*, 1970, 1976
632.8	EM & M	1.0	70	10(9.2)	130	Vassiliadis, 1971
632.8	EM & M	16	500	515	243	Ham *et al.*, 1976
632.8	EM & M	100	500	1780	840	
632.8	EM & M	1000	500	11400	5400	
632.8	M	120	70			Vassiliadis, 1974
694.3	EM	30×10^{-9}	40	0.017 (0.008)	1.35	Beatrice & Frisch, 1973
694.3	EM	30×10^{-9}	500	0.104 (0.036)	0.055	
694.3	EM	30×10^{-9}	1000	0.20 (0.13)	0.025	
694.3	M & EM	0.0015	11000	2900	3.0	Jones & McCartney, 1966
694.3	M	0.0017	70	0.5	11	Zweng *et al.*, 1968
694.3	EM	40×10^{-9}	30	0.0029	0.41	Burland *et al.*, 1978
1059	EM	15×10^{-9}	30	0.047	6.6	
1064	M	30×10^{-9}	90	0.15 (0.08)	2.4	Vassiliadis *et al.*, 1969
1064	EM	30×10^{-9}	50	0.22 (0.11)	7.6	
1064	—	6.0×10^{-6}	40	1.8 (1.1)	72	Vassiliadis *et al.*, 1968

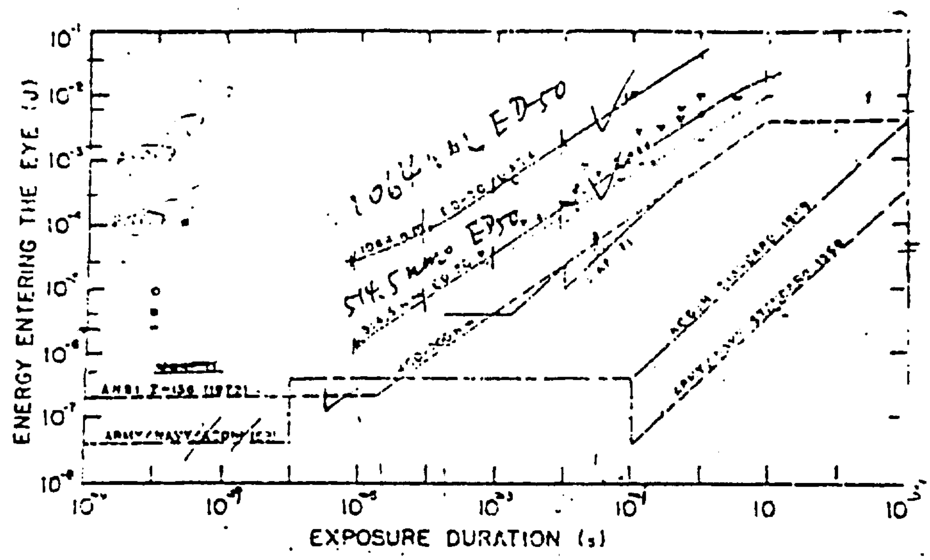
⑨ 注：EM—黄斑外照射

M—黄斑照射.

5-20 $t^{3/4}$

⑩ 重新画曲线（S型的数据难找）.

1. Table 4 ED_{50} Data from Representative Scholars of Various Nations Concerning Laser Radiation to the Eyes (unclear) 2. Wavelength 3. Radiation Site 4. Radiation Time 5. Retinal Diameter 6. Amount of Energy Entering the Cornea 7. Amount of Energy Entering the Retina (unclear) 8. Author 9. Note: EM--radiation outside of the blind spot M--radiation of the blind spot 10. Replace the graph recorder (S type data difficult) (unclear)



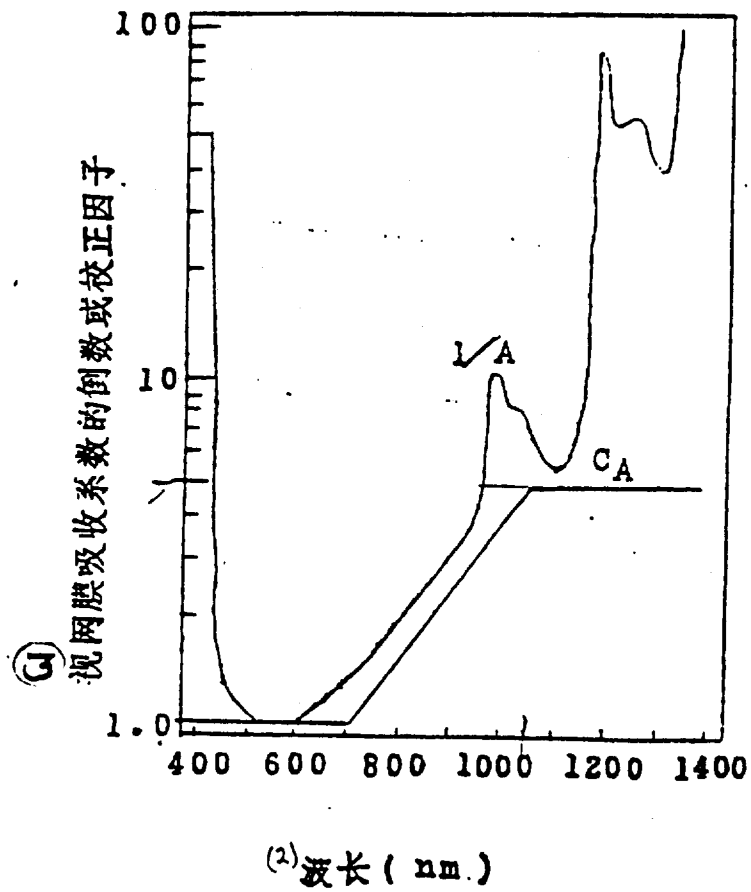
① 图2 可见和近红外激光束照射眼的视网膜损伤阈E_{50}的资料
系列

Ham *et al.* (1970) for 632.8 nm (▼); Dunsky and Lappin (1971) for 568 nm (•); Bresnick *et al.* (1970) for 514.5 nm (▲); Vassiliadis *et al.* (1971) for 532 nm (■), and for 694.3 nm (○); Vassiliadis *et al.* for 514.5 nm (◇); Lappin (1970) for 632.8 nm (▽); Naidoff and Sliney (1973) for a welding arc point source (+); Skeen *et al.* (1972a) for 1064 nm (x); and Skeen *et al.* (1972b) for 514.5 nm (•). (—) 为已报导数据中的最小值。

②

1. Fig.2 Material on the Retinal Damage Threshold ED_{50} for Visible and Infrared Laser Light Bundle Irradiation of the Eyes 2. (1) Minimum values among already derived data

$10-10^3$ seconds. Because this research has no data, it is based principally on the relevant international data. If one takes t=10 seconds and substitutes into $2.5t^{3/4}\times10^{-3}$J/sq.cm to make calculations, MPE is 14×10^{-3}J/sq.cm. (4) $10^3-3\times10^4$ seconds. MPE and the light spectrum factor C_B are related. C_B and the retinal absorption coefficient have an inverse relationship. It is possible to derive this from the relationship between the inverse of the absorption coefficient and the wavelength. (See Fig.3) 19



1. Fig.3 Retinal Light Spectrum Absorption and Correction Factors. The upper curve is the relationship between the inverse of the retinal light spectrum absorption and the degree of corneal irradiation. The Lower curve is the light spectrum correction or calibration factor.
2. Wavelength 3. Inverse of Retinal Absorption Coefficient or Calibration Factor

Infrared laser light is divided into the two parts of near infrared (700-1400nm) and the medium and far infrared (1400 ~1mm). Near infrared lasers are capable of harming the retina and lens of the eye. Moreover, the medium and far infrared laser light primarily harms the cornea of the eye.

The near infrared wave band. These experiments selected for use 1064nm laser light with irradiation times of 10^{-9} seconds, 10^{-4}, 10^{-1} seconds, and 1 second. From the ED_{50} distribution in Fig.2, one can clearly see the 1060nm because the wavelength is different from visible light. The ED_{50} value is approximately an order of magnitude larger than the wavelength of visible light. Because of this, within the range of 10^{-9}-10 seconds, MPE and the light spectrum factor C_A are related. When $\lambda > 1050$nm, C_A is taken as the constant 5. The MPE value is an order of magnitude lower than 400~700nm and is fixed to be $5x10^{-6}$J/sq.cm. In the range 700~1050 nm, these experiments have no data and consulted the international standards to set down the MPE values for two duration ranges (10^{-9}-10^{-5} second and 10^{-5}-10^{3} seconds). In these, C_A and the inverse of the retinal absorption coefficient in the 700~1400nm range are related. The expression for C_A can be derived from the curves of Fig.3. When the radiation time is in the range of 10^{-5}-10 seconds, on the basis of the ED_{50} values of these experiments, one can calculate the safety factors selected for use in the MPE to be 200~250. These coefficients are selected larger than those for the visible light band. The reason for this is that the wave length involved is relatively small. The MPE values used $12.5t^{3/4}x10^{-3}$J/sq.cm for calculations. These values also are 1.4 times higher than the international standards. 10-10^{3} seconds and 10^{3}-$3x10^{4}$ seconds showed the same effects and were refered to the international standards. [Single data (the curves may have errors)9x1.4 (unclear)].

The maximum permissible doses of medium and far infrared (eyes and skin) are divided into three time periods: (1) 10^{-9}-10^{-7} second, (2) 10^{-7}-10 second. (3) greater than 10 seconds. These experiments only have ED_{50} and MRD_{50} for 10600 nm at 1 second and 0.1 second.

①表5 远红外激光对眼损伤的ED_{50}资料

波长②	③照射时间	④实验对象	⑤角膜上光束的直径	⑥水中的吸收系数	⑦阈值或ED_{50}照射量	⑧参考文献
λ (µm)	t (s)	M–Monkey *	D_c (mm)	α_{H_2O} (cm^{-1})	H_c (J/cm^2)	
10.6	1.4×10^{-9}	R	9.5	937	0.005 (a) 0.20 (c)	Mueller & Ham, 1975
2.61-2.87	45×10^{-9}	M	0.4	3220 (?)	0.62	Egbert & Maher, 1977
1.54	50×10^{-9}	M	0.56	12	21	Lund *et al.*, 1970
2.9	1×10^{-7}	R	6.0	11190	0.004 (a) 0.3 (c)	Mueller & Ham, 1975
3.55-3.93	1×10^{-7}	M	0.48	197 (?)	1.51	Egbert & Maher, 1977
10.6	1×10^{-3}	M	2.5	937	0.8	Brownell & Stuck, 1974
10.6	1×10^{-2}	M	2.5	937	0.73	
2.795	1×10^{-2}	M	0.9	4906	0.86	Egbert & Maher, 1977
10.6	0.1	M	2.5	937	2.34	Brownell & Stuck, 1974
10.6	1.0	M	2.5	937	7.70	
10.6	900	M	10.4	937	220	Fine, 1968
10.6	1800	M	10.4	937	360	
2.7-3.0	4.0×10^{-9}	R		3220 (?)	0.004 (a) 0. (c)	Mueller & Ham, 1975
2.7-3.0	1×10^{-7}	R		3220 (?)	0.009 (a)	

⑨(a)剥蚀阈值（由瞬时超声造成的损伤，或外表皮层的脱被去除）

(c)凝固阈值

R — 兔　M — 猴

1. Table 5 Materials on the ED_{50} for Damage to the Eyes from Far Infrared Laser Light 2. Wavelength 3. Radiation Time 4. Object of Test 5. Diameter of Light Bundle on Cornea 6. Water Absorption No. (unclear) 7. Threshold Values of ED_{50} Amounts of Radiation 8. Consulted Reference 9. (a) Elimination Threshold Value (damage from the creation of instantaneous ultrasonics or the peeling off of the outer surface of the skin) (unclear) (b) solidification threshold value (unclear) B-broad M-(unclear)

On the basis of the relevant data from these experiments and the classic material available internationally (Table 5) it is possible to deduce the MPE of these wavelengths. Generally, when the wavelength is larger than $3\,\mu m$, the laser light passing through does thermal damage to the shallow layers of the cornea of the eye. When the wavelength is smaller than $3\,\mu m$, the laser light has the possibility of influencing the forward chamber and the lens body. Between 10^{-7}–10 seconds, we choose a safety factor of 1.4 - 7. The MPE value uses $0.56t^{1/4}$J/sq.cm for calculations. This value is the same as the international value. Besides this, both the two sets of irradiation times, are obtained through calculations using the formulas discussed above. For 10^{-9} - 10^{-7} seconds one uses $t=10^{-7}$ seconds to calculate MPE = 0.01J/sq.cm. In the 10 - 3×10^4 second range, one uses t=10 seconds to calculate MPE = 0.1 W/ sq.cm.

As far as the setting up of maximum permissible doses of 22
radiation from laser light on the skin is concerned, it was done on the basis of MRD_{50} values from these tests added to appropriate safety factors and calculated. Due to the fact that, for certain wave bands, we took oriental people's skin as the material for the test, the safety factors were smaller than those in the evaluations of MPE for the eyes. Generally, the range of approximately 4-20 was selected for use. MRD_{50} for these experiments was basically located between that value for white people and black people. Moreover, it was rather more toward the MRD_{50} for black people. In the case of the ultraviolet wave band, on the basis of 265nm and 308nm and for an irradiation of 10^{-9}, MPE was calculated selecting for use safety factors of 4-9. The three UVA, UVB, and UVC wave bands had actual values of equal effect, and reference was made to the World Health Organization's 1970 standards.

In the optical light and near infrared wave bands, the effects of laser light on the skin are primarily thermal effects. Within the range of 10^{-9}–10 seconds, they are related to the light spectrum absorption coefficient. Among these, the C_A calculations and the C_A in MPE for the eyes are the same.

MPE values for the far infrared are basically the same as the calculated MPE for the eyes.

As far as measurements of the maximum permissible doses of radiation for laser light irradiation are concerned, there are definite standards. For their content see Appendix A. The energy meters used in measurements as well as the power meters must either go through the national measures academy or be calibrated by the already existing measures and standards offices for the various major areas.

As far as the setting up of laser light safety protective standards is concerned, besides considering the basic principles discussed above, the cooperative teams investigated the status of contagious diseases in the various geographical areas (annex 7) and carried out a definite analysis. It is recognized that laser light irradiation has definite effects on the human eye and on the various parts of the whole body. However, with just the currently existing data it is difficult to reach a conclusion. The various international view points are in basic agreement. Even if one now carries out, using animals, a number of experiments on chronic damage, due to limitations on the means to measure widely separated effects, for the time being, it is still not possible to obtain reliable data. Considering this type of situation, we first, on the basis of data from acute tests add safety factors, and we are then able to set up standards. In the future, on the basis of accumulated data on contagious diseases, we will carry out further, more precise, revisions of the standards. Also, speaking of the international laser light protective standards which are currently in effect, they also have not been formulated in a final form. Because the wavelengths of laser light cover a broad range and there are many types of devices, whose operational forms are different, on the subject of high repeater frequency pulse laser devices, sealed type laser devices, ultraviolet laser devices, much less the X lasers of the future, there are still large amounts of biological tests which need to be done. Because of this, at the present time, this draft of standards can act as our country's initial promulgation of laser radiation health standards.

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